The Neutrino DIS: New Theoretical and Experimental Results.

A.L. Kataev
(Th. Div. of CERN/INR, Moscow)

Plan: 1 New results of the fits to xF_3 CCFR data at NNLO, N^3LO

A.L. Kataev, G. Parente, A.V. Sidorov
CERN-TH/2000-343
hep-ph/0012014

preliminary → CERN-TH/2001-58 → KPS'01
(work in progress)

Minimization of the analysis of theoretical ambigities

A.L.K., A.V. Kotikov, G. Parente, A.V. Sidorov
PLB 417 (98) 374

A.L.K., G. Parente, A.V. Sidorov
NPB 572 (00) 40 → KPS'00

2 Comparison with theoretical calculations of NS SF at $x \to 0$

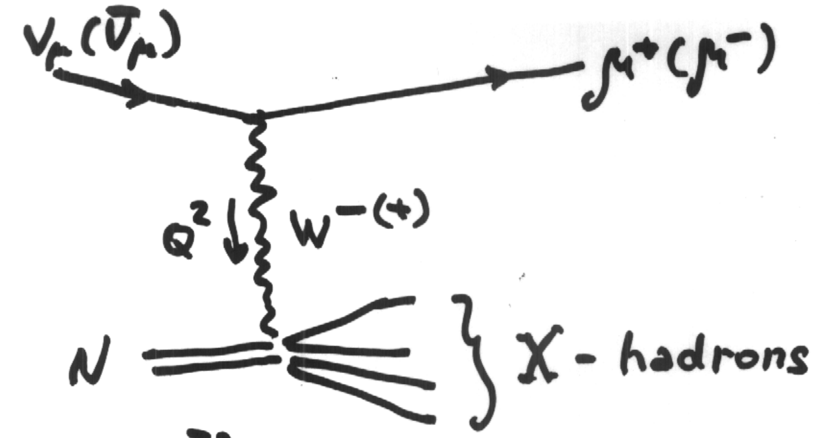
$xF_3 \sim x^b$

Ermolaev, Greco, Troyan; NPB 594 (01) 71

3 Presentation of preliminary status of νN DIS ~~data~~ data from CHORUS (CERN)

Why these data are of interest?

4 Conclusions.



$$\frac{d^2\sigma^{\nu(\bar\nu)}}{dx\,dy} = \frac{G_F^2 M_N^2 E_\nu}{\pi(1+Q^2/M_W^2)}\left[\frac{1}{2}y^2\, 2x F_1(x,Q^2) + \left(1 - y - \frac{M_N x y}{2E_\nu}\right) F_2(x,Q^2) \pm \left(y - \frac{1}{2}y^2\right) x F_3(x,Q^2)\right]$$

$$0 \le y \le \frac{1}{1+\frac{x M_N}{2E_\nu}}$$

$$0 \le x = \frac{Q^2}{2M_N E_{had}} \le 1 \qquad E_\nu = E_\mu + E_{had}$$

Usually $F_2(x,Q^2)$, $xF_3(x,Q^2)$ and $R = \left(1+\frac{4M_N x^2}{Q^2}\right)\frac{F_2}{2xF_1} - 1$ are extracted.

Theoreticians: to study influence of QCD effects and extract $\alpha_s(M_Z)$ and $\frac{1}{Q^2}$-effects need more data in different kinematical regions. Nonperturb.

Experimentalists: need more ideas what is interesting to measure and why

CHORUS: presented by R. Oldeman
Preliminary data on $F_1(x,Q^2)$, $F_2(x,Q^2)$, $xF_3(x,Q^2)$
Interesting (especially) !!
But care is needed:

3 collaborations are working in this region

Why F_1, F_2, F_3 are interesting separately?

$$F_i(x,Q^2) = F_i^{\text{Pert+TMC}}(x,Q^2)\left[1 + \frac{D_2^{(i)}(x)}{Q^2}\right] + O\left(\frac{1}{Q^4}\right)$$

possible to study Q^2-evolution within DGLAP- NNLO $\rightarrow$ $\alpha_s(\alpha_s^2)$

"Mellin moment" $\rightarrow$ NNLO

Perturbative ~~part~~ evolution $O(\alpha_s^3)$

$$M_n(Q^2) = \int_0^1 x^{n-1} F_i(x,Q^2)\,dx$$

Non-perturbative part

twist-4

There are models

"Infrared renormalon"

see Later

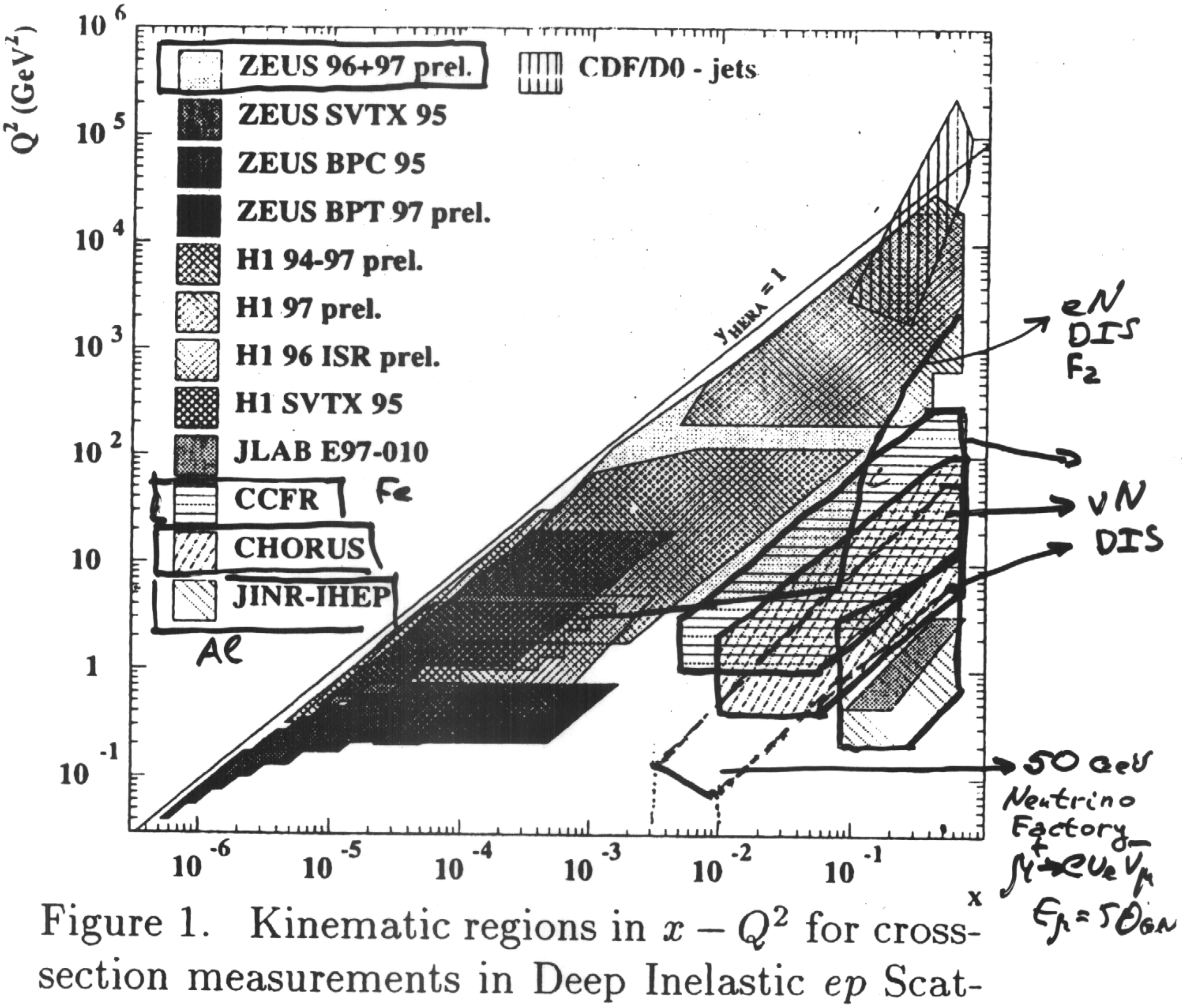


Figure 1. Kinematic regions in $x - Q^2$ for cross-section measurements in Deep Inelastic ep Scattering, ν Scattering and of triple differential jet cross-section measurements in $p\bar{p}$-collisions.

Theoretical QCD Kitchen

DGLAP equation:

$$Q^2 \frac{d}{dQ^2} F_3(x,Q^2) = \frac{\alpha_s(Q^2)}{\pi} \int_x^1 \frac{dy}{y} V_{F_3}\left(\frac{y}{x},\alpha_s\right) C_{F_3}(y,\alpha_s)$$

$$Q^2 \frac{\partial A_s}{\partial Q^2} = \beta(A_s) = -\sum_{i=0}^{2} \beta_i A_s^{i+2} \; ; \quad A_s = \frac{\alpha_s}{4\pi}$$

$\beta(A_s)$ is calculated at 4-loops
Ritbergen, Vermaseren, Larin (97)

$$C_{F_3}(y,A_s) = \sum_{n=0}^{2} C_{F_3,n}(y)\, A_s^n$$

calculated at A_s^2 van Neerven, Zijlstra (91)

$$V_{F_3}(z,\alpha_s) = \sum_{n=0}^{2} V_n(z)\, A_s^{n+1}, \text{ calculated at } A_s^2$$

$V_3(z)$-model – new
van Neerven, Vogt (00)

Moments:

$$\int_0^1 z^{n-1} V_{F_3}(z,A_s)\, dz = \sum_{i=0}^{2} \gamma_{F_3}^{(i)}(n)\, A_s^{i+1}$$

$\gamma_{F_3}^{(2)}(n)$ – 3-loops calculated analytically
at $n=3,5,7,9,11,13$ – new
Retey, Vermaseren (00)

$\gamma_{F_2,NS}^{(2)}(n)$ – 3-loops calculated analytically
at $n=2,4,6,8,10,12$
Larin, Noguiera, Ritbergen, Vermaseren (97)

$$\int_0^1 z^n F_3(z,A_s)\, dz = \sum_{i=0}^{3} C^{(i)}(n)\, A_s^{i+1}$$

$C^{(3)}(n)$ calculated analytically
at $n=1,3,5,7,9,11,13$
Retey, Vermaseren (00) – new

Used in the fits
numbers in case of $f=4$.
KPS' 01

n	$\gamma^{(1)}_{NS,F_2}(n)$	$\gamma^{(1)}_{F_3}(n)$	$\gamma^{(2)}_{NS,F_2}(n)$	$\gamma^{(2)}_{F_3}(n)\|_{wts}$	$\gamma^{(2)}_{F_3}(n)$
2	71.374	71.241	612.0598	(585)	(631)
3	100.801	100.782	(838.9272)	836.3440	861.6526
4	120.145	120.140	1005.823	(1001.418)	(1015.368)
5	134.905	134.903	(1135.276)	1132.727	1140.900
6	147.003	147.002	1242.0006	(1241.21)	(1247)
7	157.332	157.332	(1334.645)	1334.316	1338.272
8	166.386	166.386	1417.451	(1416.73)	(1420)
9	174.468	174.468	(1492.020)	1491.124	1493.466
10	181.781	181.781	1559.005	(1558.854)	(1561)
11	188.466	188.466	(1619.828)	1620.727	1622.283
12	194.629	194.629	1678.400	(1677.696)	(1679.809)
13	200.350	200.350	(?)	1731.696	1732.809

n	$C^{(1)}(n)$	$C^{(2)}(n)$	$C^{(2)}(n)\|_{int}$	$C^{(3)}(n)\|_{int}$
1	-4	-52	-52	-644.3464
2	-1.778	-47.472	(-46.4295)	(-1127.454)
3	1.667	-12.715	-12.715	-1013.171
4	4.867	37.117	(37.0076)	(-410.6652)
5	7.748	95.4086	95.4086	584.9453
6	10.351	158.2912	(158.4032)	(1893.575)
7	12.722	223.8978	223.8978	3450.468
8	14.900	290.8840	(290.8421)	(5205.389)
9	16.915	358.5874	358.5874	7120.985
10	18.791	426.4422	(426.5512)	(9170.207)
11	20.544	494.1881	494.1881	11332.82
12	22.201	561.5591	(561.2668)	(13590.97)
13	23.762	628.4539	628.4539	15923.91

How to use moments?

Jacobi polynomial method

Parisi, Sourlas (79); JINR group (87-90)

$$(*)\quad xF_3^{N_{max}} = \omega(\alpha,\beta)\sum_{n=0}^{N_{max}} \Theta_n^{\alpha,\beta}(x)\sum_{j=0}^{n} c_j^{(n)}(\alpha,\beta)\, M_{j+2}^{TMC}(Q^2)$$

$$+\frac{h(x)}{Q^2}\quad ; \quad \omega(\alpha,\beta)=x^{\alpha}(1-x)^{\beta}$$

$$\alpha=0.7;\ \beta=3.$$

$$M_{n,F_3}^{TMC} = M_{n,F_3}(Q^2) + \frac{n(n+1)}{n+2}\,\frac{M_{nucl}^2}{Q^2}\,M_{n+2}(Q^2)$$

KPS'00 $N_{max}=6 \Rightarrow 2\leq n\leq 10$ moments used

KPS'01 $N_{ax}=9 \Rightarrow 2\leq n\leq 13$ moments used

More moments = smaller theoretical uncertainties

$$M_n^{F_3}(Q^2) = \int_0^1 x^{n-1}F_3(x,Q^2)\,dx$$

Initial parameterization at Q_0^2:

$$M_n^{F_3}(Q_0^2) = \int_0^1 x^{n-2} A(Q_0^2)\, x^{b(Q_0^2)}(1-x)^{c(Q_0)}(1+\gamma(Q_0))\,dx$$

Introduces the $\Lambda_{\overline{MS}}^{(4)}$-dependence $\Leftarrow \Downarrow$ RG evolution at Q_0^2

$$\frac{M_n^{F_3}(Q^2_{exp})}{M_n^{F_3}(Q_0^2)} = \exp\left[-\int_{A_s(Q_0^2)}^{A_s(Q^2_{exp})}\frac{\gamma_{F_3}(x)}{\beta(x)}dx\right]\frac{C_{F_3}^{(n)}(A_s(Q^2_{exp}))}{C_{F_3}^{(n)}(A(Q_0^2))}$$

$$A_s(Q_0^2) = \frac{1}{\beta_0 L} - \frac{\beta_1 \ln L}{\beta_0^3 L^2} + \frac{1}{\beta_0^5 L^3}\left(\beta_1^2 \ln^2 L - \beta_1^2 \ln L + \beta_2\beta_0 - \beta_1^2\right)$$

$xF_3^{N_{max}}(x_{exp}, Q^2_{exp}) \rightarrow$ reconstructed from (*)

Fit to the CCFR xF_3 data

Free parameters: $A(Q_0)$, $b(Q_0)$, $c(Q_0)$, $\gamma(Q_0)$

$\Lambda_{\overline{MS}}^{(4)} \rightarrow \alpha_s(Q^2) \rightarrow \alpha_s(M_Z)$ $\quad \Lambda_{\overline{MS}}^{(4)} \rightarrow$ physically interest

$b(Q_0^2) \rightarrow x^{b(Q_0^2)}$

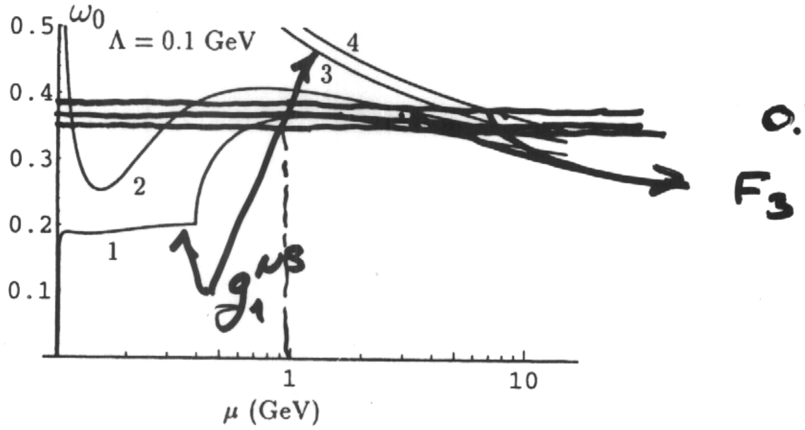
Results of the fits

order/N_{max}	Q_0^2	$\Lambda^{(4)}_{\overline{MS}}$	A	b	c	γ	χ^2/nop
NLO/9 (KPS'00= KPS'01)	5 GeV^2	341±35	4.05±0.20	0.65±0.02	3.71±0.06	1.93±0.16	87.1/86
	10 GeV^2	339±34	4.48±0.21	0.66±0.02	3.85±0.05	1.32±0.15	87.5/86
	20 GeV^2	338±40	4.67±0.15	0.65±0.01	3.96±0.07	0.95±0.15	87.6/86
	100 GeV^2	336±35	4.73±0.38	0.62±0.02	4.12±0.12	0.46±0.34	87.3/86
NNLO/9 (KPS'01)	5 GeV^2	**330±33**	**3.73±0.68**	**0.63±0.05**	**3.52±0.08**	**1.69±0.68**	**72.4/86**
NNLO/6	(KPS'00)	293±29	4.25±0.38	0.66±0.03	3.56±0.07	1.33±0.33	78.4/86
NNLO/9 (KPS'01)	10 GeV^2	**333±34**	**4.21±0.35**	**0.63±0.03**	**3.73±0.07**	**1.22±0.31**	**74.2/86**
NNLO /6	(KPS'00)	318±33	4.50±0.36	0.65±0.03	3.73±0.07	1.05±0.31	76.3/86
NNLO/9 (KPS'01)	20 GeV^2	**332±36**	**4.49±0.25**	**0.63±0.02**	**3.89±0.06**	**0.93±0.20**	**75.8/86**
NNLO/6	(KPS'00)	326±35	4.70±0.34	0.65±0.03	3.88±0.08	0.80±0.30	77.0/86
NNLO/9 (KPS'01)	100 GeV^2	**329±35**	**4.74±0.32**	**0.61±0.02**	**4.14±0.09**	**0.46±0.27**	**77.8/86**
NNLO/6	(KPS'00)	325±35	4.91±0.28	0.63±0.02	4.11±0.10	0.53±0.27	80.0/86
N^{3}LO/9 (KPS'01)	5 GeV^2	**330±31**	4.16±0.28	0.65±0.02	3.31±0.09	0.91±0.21	73.3/86
Padé/6	(KPS'00)	293±29	–	–	–	–	–
N^{3}LO/9 (KPS'01)	10 GeV^2	**329±32**	4.49±0.41	0.65±0.03	3.61±0.08	0.81±0.32	75.1/86
Padé/6	(KPS'00)	330±35	–	–	–	–	–
N^{3}LO/9 (KPS'01)	20 GeV^2	**326±32**	4.64±0.72	0.64±0.05	3.83±0.15	0.73±0.60	**76.4/86**
Padé/6	(KPS'00)	335±37	–	–	–	–	77.9/86
N^{3}LO/9 (KPS'01)	100 GeV^2	**325±33**	4.77±0.30	0.61±0.02	4.15±0.09	0.47±0.26	77.6/86
Padé	(KPS'00)	319±35	–	–	–	–	–

Compare NNLO with N^{3}LO $\Rightarrow$ effect of saturation of QCD perturbative theory predictions.

Comparision with the results of Ermolaev, Greco, Troyan (2004)

$$F_3^{NS} \sim F_1^{NS} \sim \left(\frac{1}{x}\right)^{\omega_0} \left(\frac{Q^2}{\mu^2}\right)^{\omega_0^+/2}$$



$$\mu^2 = Q^2 \Rightarrow F_1^{NS} \sim \left(\frac{1}{x}\right)^{\omega_0}$$

Obtained at ~~N~~LO resummation of $\ln(1/x)$
↓
Double logarithmic approximation

at $Q_0^2 \geq 5\,GeV^2$ KPS'01 results are Q_0^2-independent

At small μ

ω_0 - behaviour depends from

$$\frac{1}{\beta_0}\left[\frac{\ln(s/\Lambda^2)}{\ln^2(s/\Lambda^2) + \pi^2}\right] \qquad \Lambda = 0.1\,GeV$$

$$\boxed{\text{For } \; xF_3 \sim x^{1-\omega_0} \rightarrow \text{good agreement with our fits.}}$$

order/N_{max}	$Q_0^2 =$	5 GeV^2	20 GeV^2	100 GeV^2
NLO/9 (KPS'01= KPS'00)	$\Lambda^{(4)}_{\overline{MS}}$/[MeV]	379±41	376±39	374±42
	χ^2/nep	78.6/86	79.5/86	79.0
	A_2'/[GeV^2]	−0.125±0.053	−0.125±0.053	−0.124±0.053
NNLO/6 (KPS'01)	$\Lambda^{(4)}_{\overline{MS}}$/[MeV]	297±30	**328±36**	328±35
	χ^2/nep	77.9/86	**76.8/86**	79.5
	A_2'/[GeV^2]	−0.007±0.051	**−0.017±0.051**	−0.015±0.051
NNLO/6 (KPS'00)	$\Lambda^{(4)}_{\overline{MS}}$/[MeV]	–	326±35	—
	χ^2/nep	–	76.9/86	–
	A_2'/[GeV^2]	–	−0.01±0.05	–
NNLO/9 (KPS'01)	$\Lambda^{(4)}_{\overline{MS}}$	**331±33**	**332±35**	**331±35**
	χ^2/nep	**73.1/86**	**75.7/86**	**76.9/86**
	A_2'/[GeV^2]	**−0.013±0.051**	**−0.015±0.051**	**−0.016±0.051**
$\mathrm{N^3LO}$/6 (KPS'01)	$\Lambda^{(4)}_{\overline{MS}}$/[MeV]	305±29	**327±34**	326±34
	χ^2/nep	76.0/86	**76.2/86**	78.5
	A_2'/[GeV^2]	0.036±0.051	**0.033±0.052**	0.029±0.052
Padé/6 (KPS'00)	$\Lambda^{(4)}_{\overline{MS}}$/[MeV]	–	340±37	–
	χ^2/nep	–	77.2/86	–
	A_2'	–	- 0.004±0.05	–
$\mathrm{N^3LO}$/9 (KPS'01)	$\Lambda^{(4)}_{\overline{MS}}$/[MeV]	**333±34**	**328±33**	**328±38**
	χ^2/nep	**73.8/86**	**75.9/86**	**76.4/86**
	A_2'/[GeV^2]	**0.038±0.052**	**0.035±0.052**	**0.034±0.052**

stable to Q_0^2!

New!

HT - model:

$$\frac{h(x)}{Q^2} = \omega(\alpha,\beta) \sum_{n=0}^{N_{max}} \Theta_n^{\alpha,\beta} \sum_{j=0}^{n} C_j^n(\alpha,\beta)\, M^{IRR}_{j+2,F_3}(Q^2)$$

$$M^{IRR}_{n,F_3} = \tilde{C}(n)\, M_{n,F_3}(Q^2)\, \frac{A_2'}{Q^2}$$

NLO: $\alpha_s(M_Z) = 0.120 \pm 0.003(\text{stat}) \pm 0.005(\text{syst}) \pm 0.004(\text{theory})$

NNLO + $\mathrm{N^3LO}$ KPS'01: $\alpha_s(M_Z) = 0.118 \pm 0.002(\text{stat}) \pm 0.005(\text{syst})$

Preliminary → $\pm\, 0.002(\text{theory})$

Preliminary CHORUS data for F_3 - in agreement with CCFR

(11)

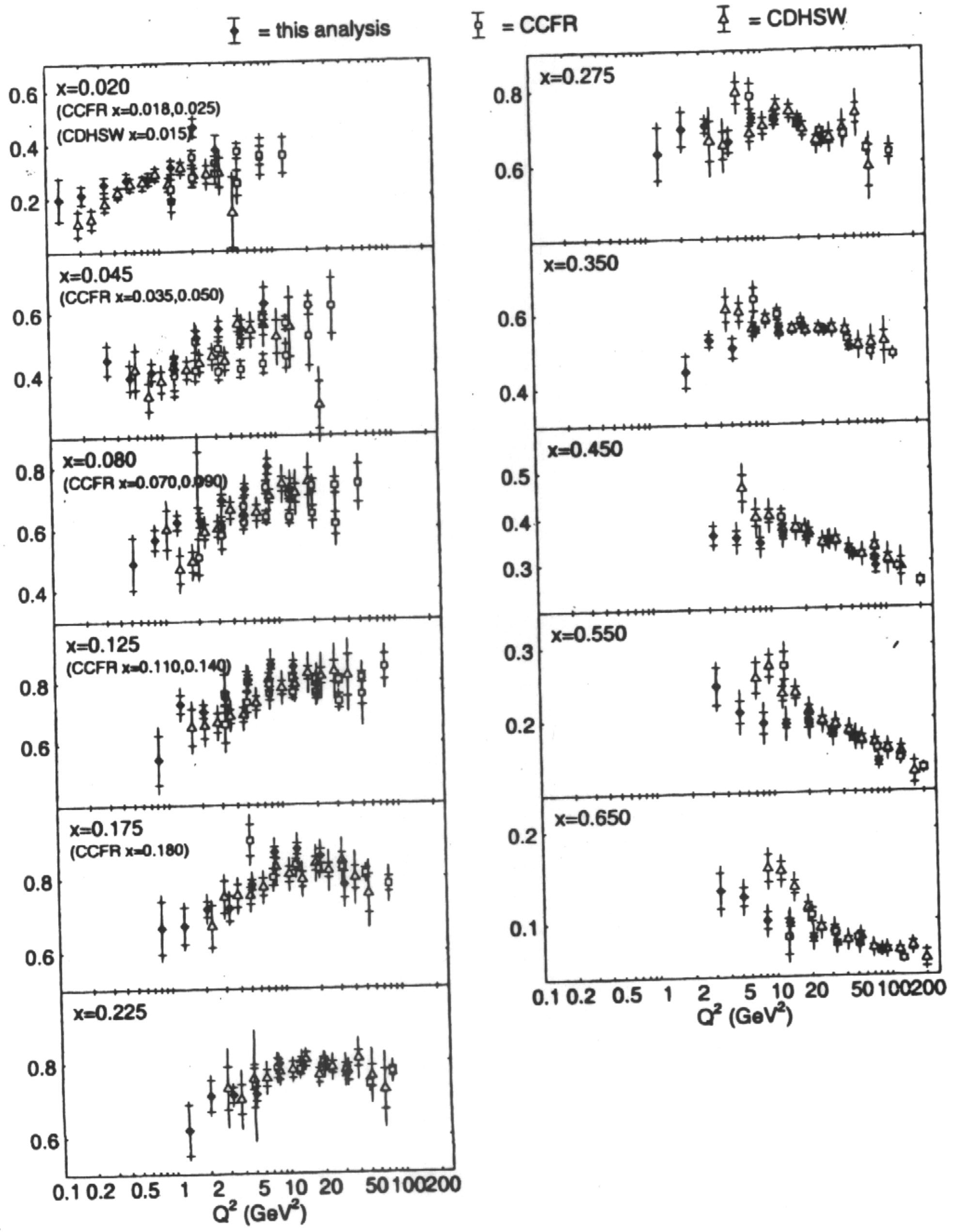


Figure 6.19: Comparison between the isoscalar structure function $xF_3^{\nu N}$ from this analysis and the results from the CCFR and CDHSW experiments.

Preliminary CHORUS data for F_2^{ν} SF in agreement with CCFR

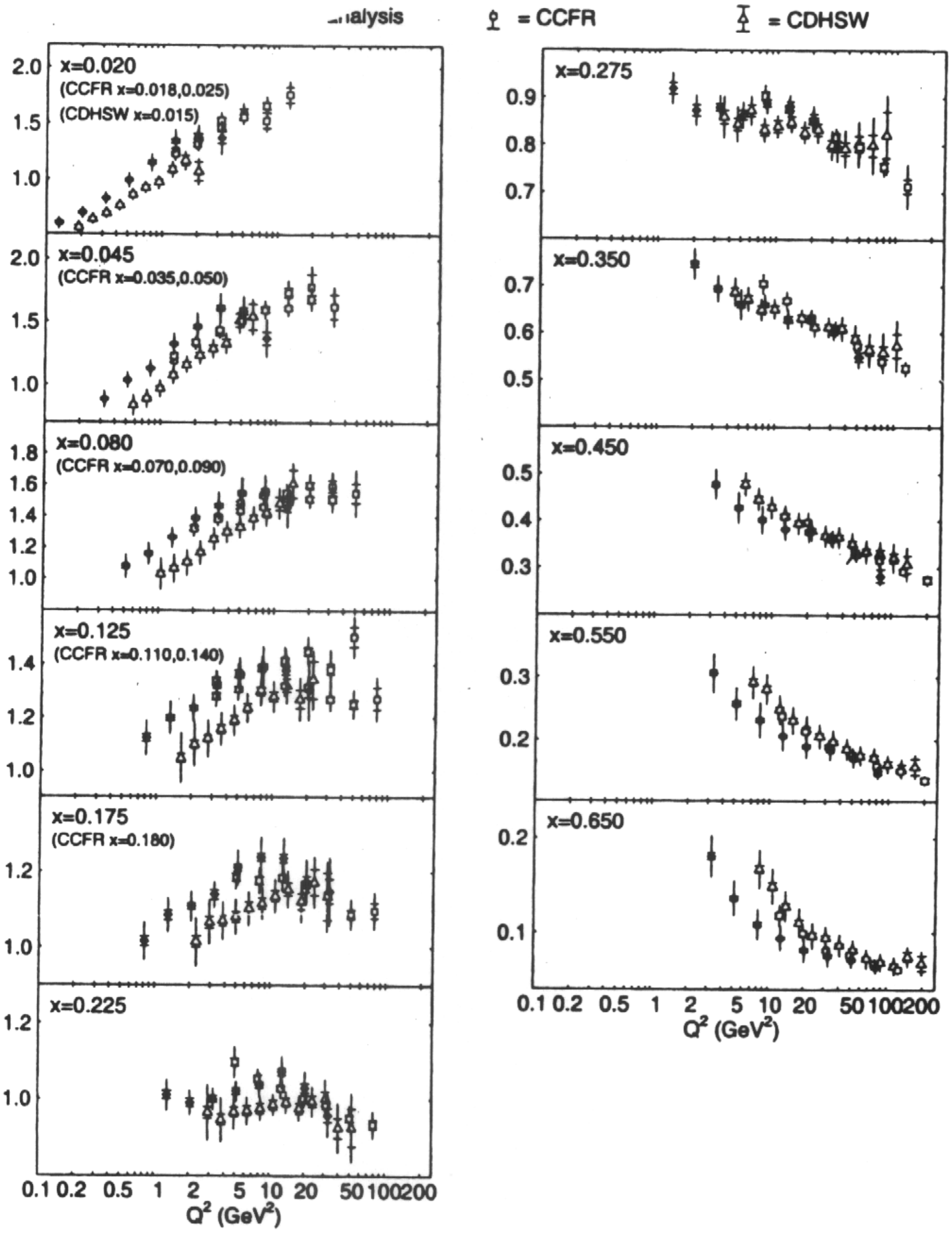
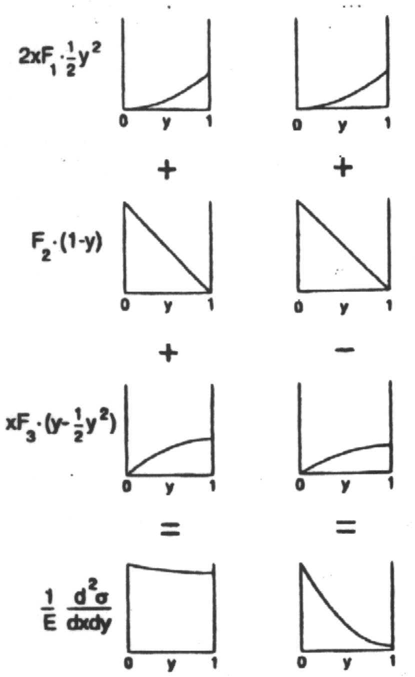


Figure 6.18: Comparison between the isoscalar structure function $F_2^{\nu N}$ from this analysis and the results from the CCFR and CDHSW experiments.

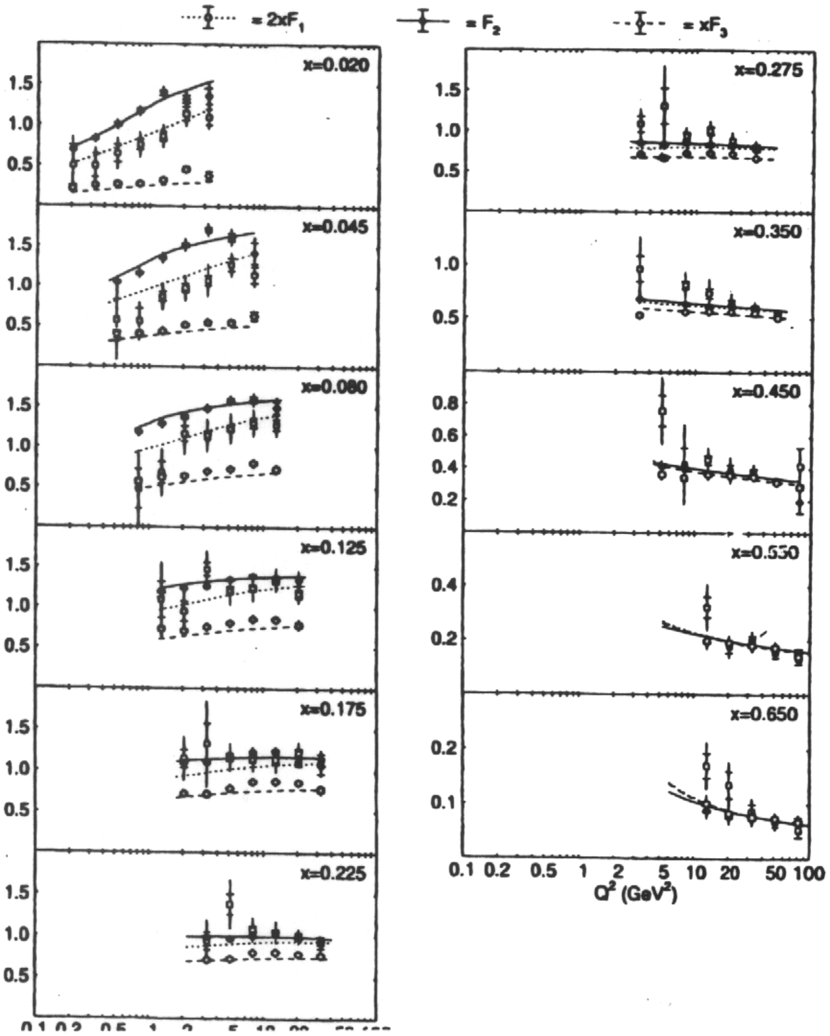
To be corrected at small x by inclusion charm-quark mass dependent effects!

Preliminary CHORUS simultaneous extraction of F_1, F_2, xF_3



Mangano et al: (A.K.K.)
DIS at NuFact.
Proposal to study unpolarized Bjorken Sum rule

$$\int_0^1 F_1^{\nu p} - F_1^{\nu n}(x, Q^2)\, dx = 1 - \frac{2}{3}\frac{\alpha_s}{\pi} - \dots$$



Why extraction of F_1 is interesting?

Dasgupta, Webber, PL B382 (1996) 273

Maul, Stein, Schäfer, Mankiewicz, PL B401 (97) 100

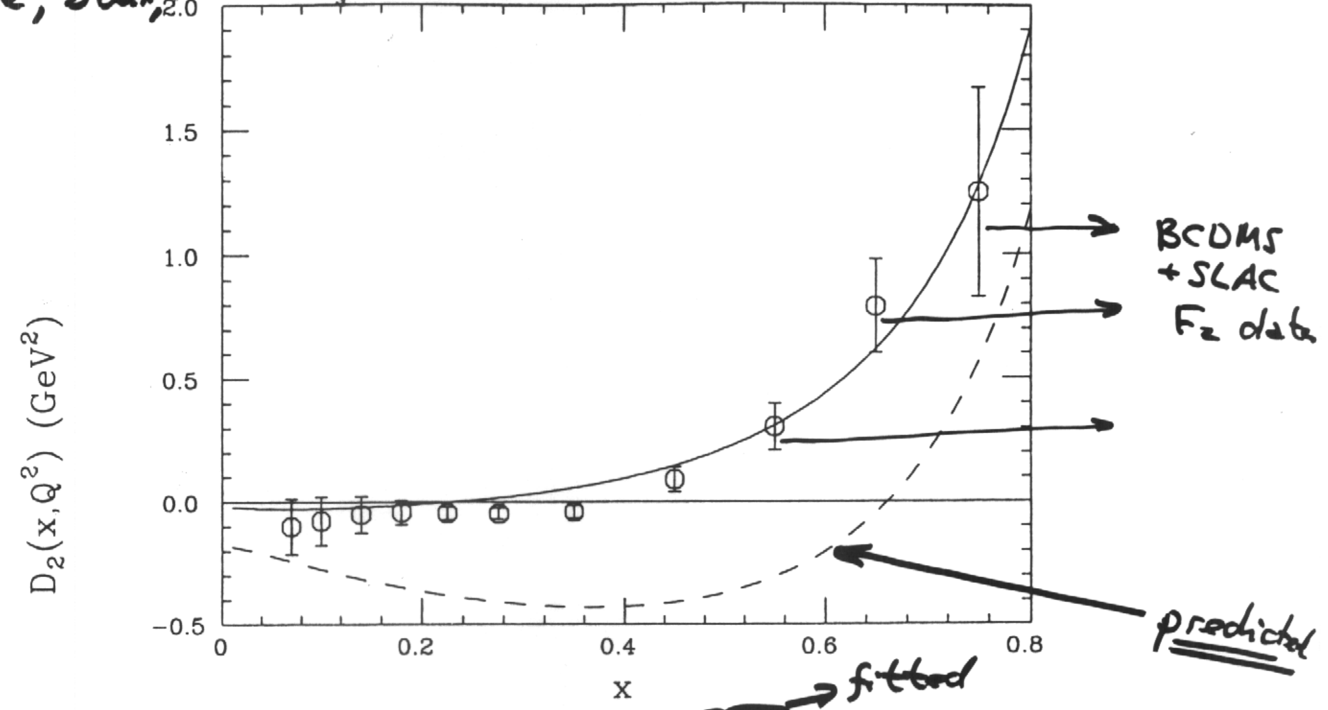


Figure 1: Coefficients of $1/Q^2$ contributions to F_2 (solid) and to F_1 and F_3 (dashed).

fitted

For F_1 and F_3 $D_i(x)$ is the same!

$$F_i(x, Q^2) = F_i^{\text{pert}+\text{TMC}}(x, Q^2)\left[1 + \frac{D_2^{(i)}(x)}{Q^2} + O\left(\frac{1}{Q^4}\right)\right]$$

$$D_2^{(2)}(x) \sim \frac{A_2'}{q(x,Q^2)} \int_x^1 \frac{dz}{z} C_2(z) \underbrace{q(x/z, Q^2)}_{\text{parton distribution}}$$

$C_2^{(2,3,1)}(x) \rightarrow$ calculated from set of diagrams

Infrared renormalon model

generate $\frac{1}{Q^2}$ - correction after resummation

Conclusions

① **KPS'00** NLO: $\alpha_s(M_Z) = 0.120 \pm 0.003\,(stat) \pm 0.005\,(syst)$
$\pm 0.004\,(theor)$

NNLO: $\alpha_s(M_Z) = 0.118 \pm 0.002\,(stat) \pm 0.005\,(syst)$
$\pm 0.003\,(theor)$

② KPS'01 prel. $\alpha_s(M_Z) = 0.118 \pm 0.002\,(stat) \pm 0.005\,(syst)$
NNLO
N^3LO. $\underline{\pm 0.002\,(theory)}$

Minimization of th. uncertainties can be seen if systematical uncert. are switched off

Alekhin (99) – method of correlation of stat. and syst.

Analysis of xF_3 CCFR: NLO
$\pm 0.0048\,(stat+syst)$

To be compared:
Santiago, Yndurain (01) → to be checked
$\alpha_s(M_Z) = 0.1153 \pm 0.0063$.

③ $b(Q_0^2)$ – Q_0^2-independent

$1 - \omega = b$
In agreement with
Ermolaev, Greco, Troyan (01)

④ New CHORUS data are interesting
$F_1(x, Q^2)$ – one of the first attempts
$xF_3(x, Q^2)$ – in agreement with CCFR
$F_2(x, Q^2)$ " — " — " — " — "
at $x > 0.25$
at $x < 0.15$ should be reanalyzed → disagreement with NMC
CCFR – not – already reanalysed.

Intergettion with CCFR due to Moriond

① 1992 → first discussion with M. Shaevitz

1993 - 1996 – useful e-mail contacts

② 1997 → First presentation at Moriond of the K., Kotikov, Parente, Sidorov work

Discussions with CCFR

③ 2000 - Presentation at Moriond KPS'00 work (Sidorov)

<u>Conclusion</u>: We gained a lot from contacts with CCFR/NuTeV represent. at Moriond

Thank you, Tran

Tribute to Tran

24 - 26 May, 2001

Conference at ITEP

④ 2001 – Intersection with CCFR/NuTeV at La Thuile

Thanks to Organizers.